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ARIZONA INTELLIGENT VEHICLE RESEARCH PROGRAM – PHASE ONE: 1997 - 2000

This report documents the first three years of a research program to study possible practical applications of infrastructure-based and vehicle-based Intelligent Transportation systems. The Arizona Transportation Research Center (ATRC) performed this project as an in-house research effort of the Arizona Department of Transportation (ADOT).

During Phase One of this project, from 1997 to mid-2000, ADOT forces and the ATRC have reviewed, tested, evaluated and demonstrated many Automated Highway System (AHS) and Intelligent Vehicle (IV) concepts. These new resources may improve the efficiency of Arizona's highway system, and in particular, may enhance the safety and efficiency of ADOT's winter maintenance operations.

Project Background

This report summarizes two distinct areas of research activity. Section One is a general review of the project's inspiration and goals, and it discusses early AHS efforts in Arizona.

Section Two of this report describes in detail Arizona's winter maintenance needs and goals that led to a long-term snowplow evaluation partnership between ADOT and Caltrans. This section discusses the specifics of site selection and construction of the Arizona intelligent infrastructure site. It also details the snowplow testing and evaluation, and the Phase One results, conclusions, and recommendations from this project for future research.

Section I – Project Genesis

Intelligent Transportation Systems (ITS) technology promises to improve both safety and efficiency on the highways. In the early 1990's, with support from the US Department of Transportation (DOT) and Federal Highway Administration (FHWA), several progressive states and public-private groups began work on applications of ITS research for problems of a local or regional nature.

On-board vehicle systems and infrastructure technology are the key elements of Automated Highway Systems. "Demo '97," an AHS feasibility showcase, was held in San Diego. This seminal exhibition was the showcase for a variety of advanced vehicle technology research programs. The "Demo '97" effort focused on enhancements to safety and reduction of traffic congestion, offering individual and interrelated solutions for heavy commercial trucks, transit buses, and light vehicles.

The three core AHS / IV solutions developed and demonstrated were:

- Adaptive Cruise Control
- Collision Avoidance
- Lane-Keeping Systems

Adaptive cruise control senses vehicles in the lane ahead and adjusts speed accordingly.

Collision warning and avoidance systems detect objects ahead and can warn the driver, as well as initiating braking or maneuvering.

Lane-keeping systems use sensors or cameras to follow markers in the roadway, and can warn the driver or steer the vehicle.

Even in 1997 these three fundamental AHS technologies were represented by fully developed prototypes, with great potential for improved efficiency and safety.

The Turning Point

The Arizona delegates attending “Demo ‘97” saw the potential benefits of AHS very clearly. It showed the basic technical feasibility of fully automated systems, and also the potential for real near-term benefits from semi-automated vehicle technologies.

As one of ADOT’s senior managers reported, “AHS is a key component of next-generation U.S. surface transportation. Understanding the AHS feasibility and technology will provide ADOT an early opportunity to evaluate this system and its application to the future of Arizona’s congested highways.”

I-10 Tucson-Phoenix Corridor Study

In late 1997, ADOT funded a concept study to explore AHS / IV applications to Arizona transportation issues. A major goal was to win support and sponsorship for AHS research.

This study focused on the high-traffic Tucson-to-Phoenix segment of Interstate 10, using a phased approach to develop this route as an intelligent highway corridor.

The research team also studied the structural design issues for the proposed I-10 roadway sections, and the infrastructure issues involved in supporting AHS / IV technologies.

The results showed that overall costs would not be radically higher than for the anticipated requirement of new lanes in 2005 and in 2020.

Mini-Demo Projects

ADOT also developed plans to bring two separate intelligent vehicle concepts into the metropolitan Phoenix area for public Demos. The first AHS demonstration was California’s PATH system, with fully automated cars guided by buried magnetic markers. For this event, a dedicated closed-course test site was constructed. A total of about 200 people were given rides in the automated PATH cars.

In response to an exit survey, over 90 percent of the guests reported that the ride had been a positive experience and that they would like to use these AHS technologies in the future. The greatest benefit of AHS was seen as increased safety, while concerns involved control in an emergency, and, relying solely on a computer.

The second IV concept exhibition to be scheduled was the Carnegie-Mellon machine vision guidance system, which could be demonstrated on public roadways. This event was conducted in January 1998, with a smaller group of guests, and similar levels of success.

VISTA Research Partnership

The VISTA Project was a direct result of early AHS demonstrations in Arizona, and the I-10 Intelligent Express Lanes study. The state’s Legislature appropriated funding in June 1998 for an intelligent vehicle research center, which was established at the University of Arizona.

The primary goal of VISTA was “…to develop an affordable vehicle that can be deployable within the next 5 – 10 years.” The most critical objective was to develop and demonstrate a fully automated Arizona-based vehicle, which took place in April 1999. The project went on to expand its database and seek future support.

Summary: ADOT’s AHS Efforts

ADOT has been involved in many regional and national AHS / IV activities. The basic intent is to explore and develop effective solutions to transportation problems on the state’s highway system. A second global goal is to represent long-term interests of the smaller state DOTs.

Section II – Snowplow Research

ADOT's goal was to join a national intelligent vehicle / automated highway partnership, to gain the most benefit from a partner's funding and R&D facilities of such an effort. In return, ADOT's primary assets were its unique mix of weather, terrain, highways and personnel.

Arizona's Critical Contribution

The key accomplishment in Phase One of the project was to develop a working partnership with Caltrans (the California Department of Transportation), whose Advanced Snowplow (ASP) program offered benefits to both states.

Arizona's key commitment to the project was a second, independent test site facility, where ADOT would install several miles of PATH magnets for tests of the ASP plow. Arizona also would fund the shipment of the snowplow, and technical support during the tests. At least one month of training, testing and evaluation was planned for the Arizona site each winter.

The Caltrans-ADOT ASP snowplow features lane position and lane departure warning, plus a collision warning system. A continuous line of magnetic markers embedded in the roadway provides position data to the snowplow.

Arizona's decision to install Caltrans magnets raised many questions. One basic issue was the effect of drilling thousands of holes and embedding magnets in the roadway. To assess the real-world performance of the magnets and sealants, ADOT developed test sites, with a short section of magnets on the lane centerline.

Magnets were installed at six sites on Interstate 40 across northern Arizona, and each site was inspected after 6 and 18 months. The materials showed no visible degradation, nor was there any negative effect to the pavement. These results confirmed the choice of products and methods for the ASP test site near Flagstaff.

Snowplow Test Site Selection

Several locations across northern Arizona were considered for the PATH magnet testing. Compared to the Caltrans test site at Donner Summit, every significant characteristic of the Arizona location had to be distinctly different.

US 180 at Kendrick Park near Flagstaff was chosen for its climate history, accessibility, traffic counts, and strategic visibility. US 180 is a main tourist route to the Grand Canyon, regardless of the weather or season.

Kendrick Park is at 8,000-foot elevation, with an average snowfall of about 100 inches. The level, open terrain has nearly constant winds that create major snowdrifts and whiteouts.

Roadway Magnet Installation

In the first year, 1998, the project was funded to install a total of four miles of magnets on the lane centerline of US 180, a rural two-lane asphalt roadway. In 1999, two more lane-miles of magnets were installed.

This six mile intelligent vehicle infrastructure consists of 8,037 discrete magnetic markers, each with four embedded ceramic magnets. Records show that the installations were done in approximately 21 workdays of 10-hour shifts. This is about 3.5 days per lane-mile with a crew averaging about 14 men.

Snowplow Partnership Operations

Arizona terrain, winter conditions, snowplows, operator training, and maintenance practices are all quite different from those of California. The Arizona operator pool is a key asset for the California program. ADOT's drivers provide a vital third-party viewpoint on the ASP system at each stage of its development.

During the winter testing and training period, ADOT wanted to expose as many of its drivers as possible to the concepts and abilities. It was also important for ADOT to use and evaluate the Caltrans snowplow in normal winter storm operations. The work plan focused equally on both of these aspects of the research activity.

For ADOT, the best approach for operator training and field evaluation was with a core group of Team Leaders. These local operators were the key interface between the snowplow, the Caltrans technicians, and operators from ADOT maintenance camps across northern Arizona. The Team Leaders explained, demonstrated and trained the students on the ASP systems. They also prepared, fueled and checked the vehicle, did start-up systems tests, and coordinated with Caltrans team members on trouble-shooting. Finally, they were encouraged, but not required, to use and evaluate the Caltrans ASP in winter storms.

Arizona Results: First Two Years

Quantitative research results for ADOT in Phase One of this ASP project are limited, but the qualitative conclusions are significant. Some 30 ADOT snowplow operators gained experience with state-of-the-art lane guidance technology. Significant plowing was done on US 180 during storms in both winters, and the ADOT Team Leader operators reported good overall ASP system results in every case.

Ratings of the ASP lane-awareness system were high among the Arizona operators. This may reflect difficult Arizona winter operating conditions and frustration with snowplowing visibility. ADOT operators also ranked the display screen highly, although they had many suggestions on how to improve the features.

Ratings of the ASP collision warning radar were relatively low. ADOT comments focused on the obvious need for the system to function on two-lane highways with oncoming traffic.

Vehicle System Cost Results

After two years of research and operational development of the system, costs for the ASP package are becoming clearer. The current (mid-2000) estimate for a future production unit is from $25,000 to $30,000. A related finding is that stand-alone collision warning and vehicle-tracking systems are low-cost ways to improve safety and efficiency for fleet vehicles anywhere, with no infrastructure cost.

Roadway Infrastructure Cost Results

Caltrans reports the cost of installation to be $25,000 per mile in concrete, including the surveying, installation, and magnets. In the future, they estimate that contractor costs may be reduced to near $18,000 per lane mile.

For the US 180 site, ADOT developed cost figures that were effectively repeated from the first to the second years. Installation of six lane-miles of magnets by ADOT forces was done at an average cost of $17,500 per lane mile of asphalt highway, in 1998 and 1999. This is based on ADOT's internal labor costs, averaging $12.00 per hour with burdens. Installation costs must also be balanced with the design lifespan of the roadway. Overlays can extend the life of a highway for many years, but eventually it must be rebuilt, and the embeds must be replaced.

Project Benefits

ADOT's more subjective results are also clear. In return for the independent test site and an active role in testing, ADOT gained its own perspective on the suitability of ASP concepts for wider use in Arizona. Transfer of the only existing ASP prototype snowplow to Arizona, for up to a month during each winter, offers a priceless opportunity to inform the managers and maintenance staff at every level of ADOT.

Recommendations & Conclusions

ADOT plans to continue with Caltrans in joint project activities to refine the ASP systems. The research goal is commercialization at a reasonable cost. There is also a strong interest in equipping an ADOT fleet snowplow with advanced guidance equipment, if it is feasible.

One key conclusion from this Phase One of the advanced snowplow research is that while ASP systems offer real advantages to snowplow operators and to the public, costs will always be an obstacle to deployment. For a rural state such as Arizona, these roadway infrastructures and vehicle systems may be practical only in the most critical locations of the state.

Note: The full report on this project, Arizona Intelligent Vehicle Research Program – Phase One: 1997-2000, by Stephen Owen of the Arizona Transportation Research Center (Arizona Department of Transportation, report FHWA-AZ-01-473(1), dated February 2000) may be obtained from ATRC as listed below.